

<<基本粒子及其相互作用>>

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作者：（加）金广浩 著

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## 前言

The last few decades have seen major advances in the physics of elementary particles. New generations of particle accelerators and detectors have come into operation, and have successfully contributed to improving the quantity and quality of data on diverse interaction processes and to the discoveries of whole new families of particles. At the same time, important new ideas have emerged in quantum field theory, culminating in the developments of theories for the weak and strong interactions to complement quantum electrodynamics, the theory of the electromagnetic force. The simplest of the new theories that are at the same time mathematically consistent and physically successful constitute what is known as the standard model of the fundamental interactions. This book is an attempt to present these remarkable advances at an elementary level, making them accessible to students familiar with quantum mechanics, special relativity, and classical electrodynamics. The main content of the book is roughly divided into two parts; one on theories to lay the foundation and the other on further developments of concepts and descriptions of phenomena to prepare the student for more advanced work. After a brief overview of the subject and a presentation of some basic ideas, two chapters which deal mostly with relativistic one-body wave equations, quantization of fields, and Lorentz invariance follow. In the spirit of the practical approach taken in this book, a heuristic derivation of the Feynman rules is given in the fourth chapter, where the student is shown how to calculate cross-sections and decay rates at the lowest order. The following chapter contains a discussion on discrete symmetries and the concept of symmetry breaking. Isospin is introduced next as the simplest example of internal symmetries in order to ease the reader into the notion of unitary groups in general and of  $SU(3)$  in particular, which is discussed next together with the recent discoveries of new particles. The next two chapters present the standard model of the fundamental interactions. We make contact with experiments in subsequent chapters with detailed studies of some fundamental electroweak processes, such as the deep inelastic lepton-nucleon scattering, the CP violation in the neutral K mesons, the neutrino oscillations and the related problem of the solar neutrino deficit, and finally, the  $\tau$  lepton decay, which touch upon many aspects of weak interactions. The very high precision of the data that is now attained in some of these processes requires a careful examination of higher-order effects. This leads to a detailed study of one-loop QCD corrections to weak interactions. The next chapter demonstrates the remarkable property of asymptotic freedom of quantum chromodynamics and introduces the powerful concept of the renormalization group which plays a central role in many phenomena. The heavy flavors of quarks, which pose new questions on several aspects of interactions and could open windows on the 'new' physics, form the subject of a separate chapter. We close with a review of the present status of the standard model and, briefly, of its extensions. Selected solutions to problems are given. Finally, important formulas are collected in an Appendix for convenient reference.

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### 内容概要

The last few decades have seen major advances in the physics of elementary particles. New generations of particle accelerators and detectors have come into operation, and have successfully contributed to improving the quantity and quality of data on diverse interaction processes and to the discoveries of whole new families of particles. At the same time, important new ideas have emerged in quantum field theory, culminating in the developments of theories for the weak and strong interactions to complement quantum electrodynamics, the theory of the electromagnetic force. The simplest of the new theories that are at the same time mathematically consistent and physically successful constitute what is known as the standard model of the fundamental interactions. This book is an attempt to present these remarkable advances at an elementary level, making them accessible to students familiar with quantum mechanics, special relativity, and classical electrodynamics.

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作者简介

作者：（加拿大）金广浩 Quang Ho-Kim Pham Xuan Yem

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## 章节摘录

插图：1.4 Symmetries The recent history of physics gives us several examples that illustrate the importance of the symmetry considerations in explaining empirical observations or in developing new ideas. Thus, the intriguing regularities found in the atomic periodic table can be naturally explained as resulting from the rotational symmetry that characterizes atoms in their ground states; similarly, the relativity theory owes the clarity and the elegance of its formulation to its guiding principle, Lorentz invariance. However, more than any other field, particle physics, perhaps because of the very nature of the subject or because of the absence of relevant macroscopic analogies or useful classical correspondences, has by necessity conferred upon the symmetry concept a key role that has become essential in formulating new theories. The existence of the Q-particle and the reality of quarks are two outstanding demonstrations of the power of this line of reasoning, but no less impressive is the prediction of the existence of the electronic neutrino by Wolfgang Pauli back in 1930 solely on the basis of the conservation of energy, momentum, and angular momentum, the validity of which was still in doubt at the time. Pauli took a road less traveled by and opened up a whole new world. The prominent place taken by the symmetry considerations throughout this book only reflects their importance in particle physics. In this section, we will sketch a general picture of the idea, and briefly define various symmetry operations. As we have seen above, every particle is identified by a set of quantum numbers. These numbers summarize the intrinsic properties of the particle and, for this reason, are called the internal quantum numbers, meaning that they have nothing to do with the kinetic state of the particle, which is described by other conserved quantities that depend on the state the particle is in, such as the energy, momentum, or angular momentum. The existence of a quantum number in a system always arises from the invariance of the system under a global geometrical transformation, that is, one that does not depend on the coordinates of the space-time point where it is applied. A simple example suffices to illustrate the general situation. Consider two particles in a reference frame in which their interaction energy depends only on the relative distance of the particles. It follows then, first, that a displacement of the origin of the coordinates by an arbitrary distance produces no measurable physical effects on the system, and second, that the total momentum of the system remains constant in time because its rate of change, given by the total gradient of the interaction energy, is strictly zero. So, generally, if we have a physical system in which the absolute positions are not observable, the energy depends on the relative distance rather than on individual particle positions, and if we apply on it a geometrical transformation (spatial translation), then we obtain as direct consequences the invariance of the system to the applied transformation (translational invariance) and the existence of a conservation rule (momentum conservation). These are, in short, the interdependent aspects found in every symmetry principle.

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